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Micro-Bunching the AGS Slow External Beam*

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Abstract

Measurements and modeling are presented on BNL's AGS operation of the slow External Beam with sub-nanosecond beam bunching for the full two second spill.

1 Introduction.

The Brookhaven AGS can now operate with a few hundred pico-second beam bursts in its Slow External Beam. "Micro-bunching" was developed to meet the requirements of a new generation of users:[1] 1) About 100 pico-sec RMS bursts every 50 nano-second for time of flight momentum determination of incoming GeV/c level Ko's to measure the $K_L \rightarrow \pi^o . \nu . \bar{\nu}$ branching ratio. 2) A bunched beam with 30 pico-sec bursts to "prebunch" Kons for a 12 GeV/c RF separated beam to eliminate the first bunching cavity section, increasing the K flux per proton and shortening the secondary beam. And 3), Sub-nanosecond bursts would be appropriate in test beams for collider detectors.

In 1980 Ch Steinbach and R Cappi used the 200 MHz SPS prebunching cavity in the PS to reduce the low frequency (<1 KHz) ripple on the PS spill. RF structure as an undesirable side effect was expected, not found to cause the users problems, and thus not investigated [2]. Bunching is achieved by forcing a debunched beam between empty barrier buckets at the extraction radius. We presently use the 93 MHz longitudinal dilution cavity. With 20 KV per turn on this cavity, modeling predicts 130 pico-second bunches with ~11 nsec spacing; at present, bunches of 330 ps have been seen with high intensity protons and 250 ps with ions.

2 Longitudinal Modeling

The first test with Heavy Ions showed <2.5 nsec bunches and spill ripple reduction over a surprising four kilo-Hertz variation in VHF frequency. Another early run with protons showed less than 0.6 nsec bunches, over about a hundred Hertz range. To better understand these observations we required a computer simulation of longitudinal motion of beam in the AGS with this setup.

The equations modeled are given in Ref 3. Normal conditions used were: VHF (93 MHz) voltage = 20 KV & $\dot{B}/B$ = 0.002 /Sec., producing buckets with the following: stable phase = 0.35^o , half height = 10 KV, & length = 344^o (a 16^o or 0.48 nsec gap between buckets). Particles were started well out of the bucket with a large $\dot{\phi}$. Location of a particle was plotted every 20 micro-sec equivalent (.01 radians of synchrotron oscillation) as a small dot. To better demonstrate this motion, Fig 1 is plotted with 15 times normal $\dot{B}/B$ (or one fifteenth RF voltage) to separate trajectories. The approximate location of part of the separatrix around the empty bucket and beyond is sketched in as solid lines]. As the AGS field falls, the particle spirals out since it is not in a bucket. Being above transition energy, $\dot{\phi}$ decreases with increasing radius. At a particular radius the transverse tune reaches 8 2/3, and the particle is extracted. The $\dot{\phi}$ where extraction occurs is the difference between the frequency associated with extraction and the RF frequency. This $\dot{\phi}$ can be adjusted, thus as the beam could be set up to extract at any $\dot{\phi}$. The particle phase is recorded for many different $\dot{\phi}$'s for the first pass through that particular value (the emphasized points on Fig 1 show these "first crossings" of the extraction radii). Note: $\dot{\phi}$ in these figures is "normalized" to the synchrotron frequency of 235 Hz and the phase is offset by pi/2 to better see the gap between buckets.

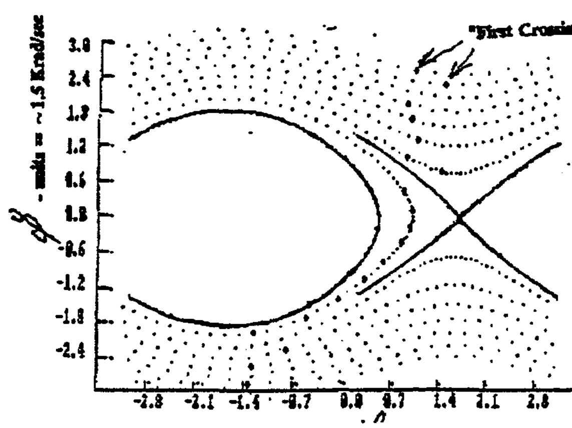

Figure 1 Particle Trajectory Between the Buckets,

Fig 2 shows the "first crossing" (large dots Fig 1) results for 300 particles evenly spaced phases at an initial The first crossing of each of a series of momenta, shown as a series of short lines of many dots of slightly different phases at different phi dots..

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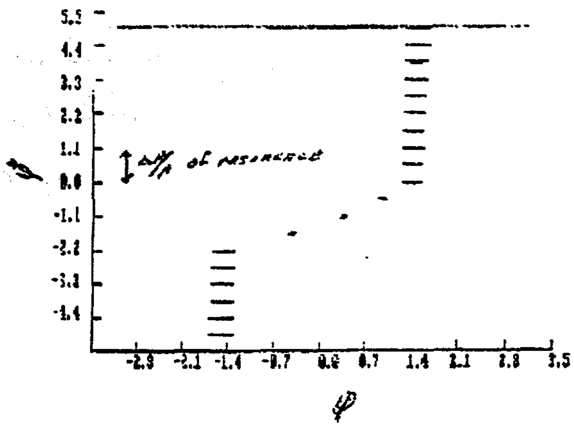

Figure 2 First crossings for 300 Particles

The assumption is that when the beam crossed the transverse resonance, the beam will be extracted almost immediately. Thus the distribution in phase at many possible extraction resonance radii were plotted. Fig 3 shows a histogram of particle population versus time.

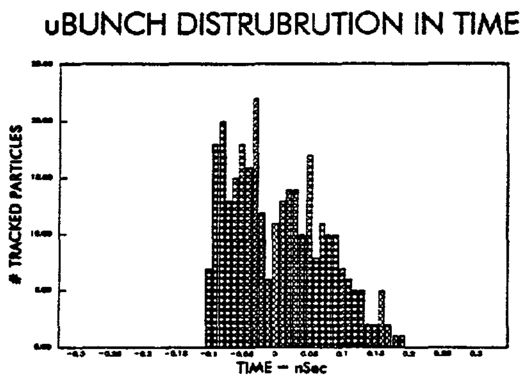

Figure 3 Histogram of Particles at Extraction vs Time

One result was that the beam will be bunched at the 120 psec level over a broad range of frequencies implies spill structure reduction over this range as it is inversely related to bunch length [Ref 1]. Another was that bunch widths of 30 pico-seconds RMS can be seen if the bucket is centered above the extraction radius. These results do require that all particles are quickly extracted together. This assumption is not completely valid. There are two corrections required.

2.1 Momentum width

The actual transverse tune of a particle is dependent its transverse oscillation amplitude. This amplitude distribution implies a momenta range of 2 parts in 10^4 (this extent in $\dot{\phi}$ is shown on Fig 2). The phase of the extracted beam is a mixture of $\dot{\phi}$'s and their various phases thus making the bunches wider. This correction is large is just below synchronous frequency, unfortunately where the bunches appear narrowest.

2.b Transverse Modeling Delay in extraction -

There is some difference in the time to extract particles of the same momentum, broadening the bunches as a function of phi dot. The details of the transverse modeling and initial conditions are discussed in another paper [3].

For each particle, the time to extraction (blow-up), was recorded if it wasn't retrapped. The average and RMS spread in delay time was calculated. These trackings were done for various rates tune change. A plot of variation in delay versus $\dot{Q}$ (Fig 4) shows that the product

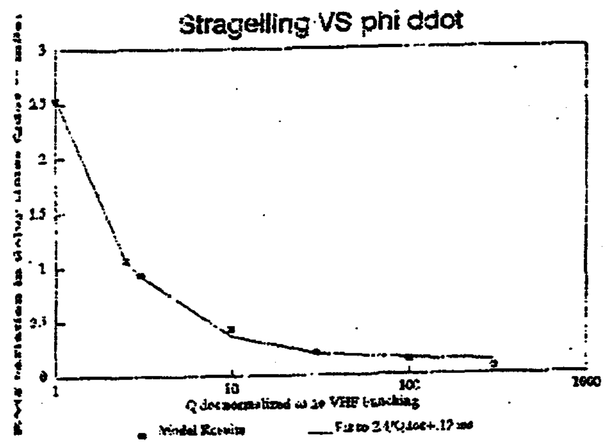

Figure 4 Spread in Time to Extraction

is invariant over the range of interest. The spread in

Histogram of Particles at Extraction vs Time

delay to extraction multiplied by $\dot{\phi}$ for the resonance causes an added spread in phase, and thus bunch width.

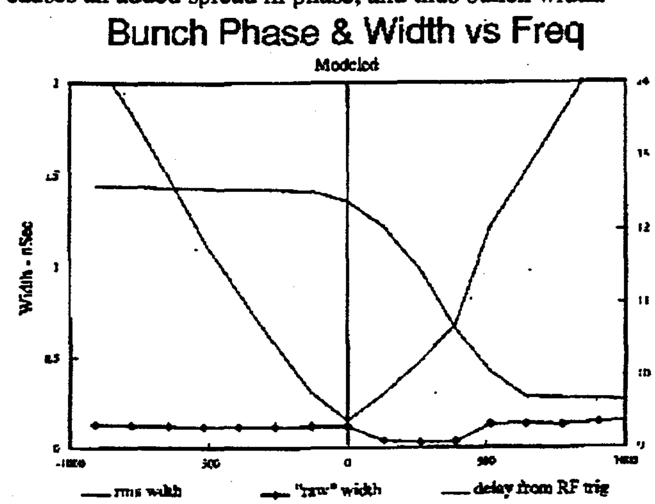

Figure 5 Phase and Width

This effects bunch width if the bucket is not synchronized, thus widths of 130 psec are still expected over about +/- 50 Hz. At larger phi dot's the effect will be large and bunching should disappear. This result is added to width expected from longitudinal modeling is plotted in Fig 5 with the "raw" widths from longitudinal modeling. During the tune-up of VHF cavity frequency, narrow bunches were not seen at frequency differences that still resulted in reduced spill structure.

The above modeling was also done for an 80 KV VHF RF system, four times the present voltage. The minimum predicted width here is 80 psec RMS or 62% of the width at 20 KV, consistent with the 50% expected from simple calculations.

3. Experimental Results

Bunch widths were measured using fast (<100 ps) counters in an electron beam looking at the Slow Beam. The timing trigger was a discriminator fed by a RF signal from the cavity. The delay relative to the trigger for each electron was recorded. Scatter plots of electron delay vs time into the spill showed a variation in width during the spill. The middle 15% of the spill was separately analyzed. Runs was taken for a selection of frequencies in the VHF cavity. Average time delay, "phase" and variation in delay "width" are plotted verses the frequency over the results of modeling; the zero frequency was chosen to match minima in width and the delays were matched at mid frequency. The is good agreement in the variation in phase and the shape of the width curve. The widths are almost twice expected..

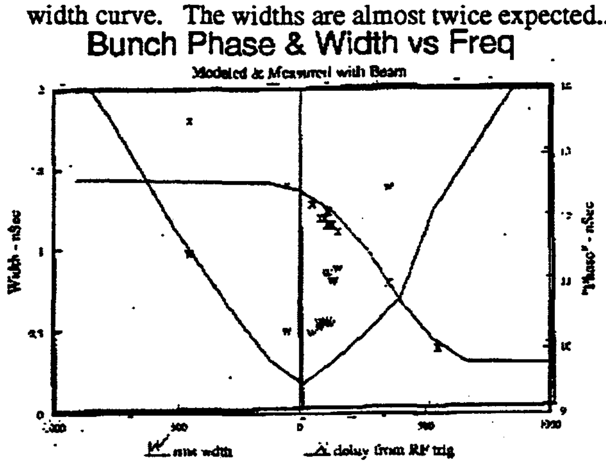

Figure 6 Model and Data [X W]

Also installed for this test was an old 200 MHz acceleration cavity, modified to resonate at 186 MHz, to be used as a bunching detector. It generated over a volt of signal with the 5 microAmps in the SEB. The hope is to use the phase of this signal to servo the extraction frequency

The last run was made with Gold ions into a few micron thick quartz cherenkov counters, good to 50 pico-sec. Also installed: a phase locked loop on the RF to reduce noise and a step recovery diode before the discriminator to sharpen timing. Widths for this run were as low as 250 pico-seconds. Note that the time distribution is more symmetric than the model prediction.

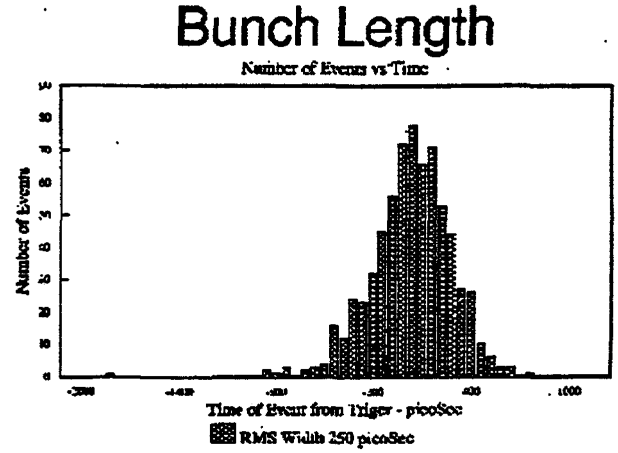

Figure 7 Time Histogram of Events

Again there was a drifting of the width over the spill and at rates up to few tens of hertz.

To achieve ~100 ps widths with 50 ns spacing between bunches, a low frequency RF system cavity will be provided for bunch spacing and the 93 MHz cavity, with possibly a 200 MHz one, to sharpen up the bunches. Foe 30 ps bunches the 200 MHz cavity will be run at ~100 KV.

References

[1] AGS 2000 Workshop Proceedings, BNL 52512, 1996

[2] Cappi & Steinbach "Improvement of the Low Frequency ..." CERN/PS/OP 80-10 & IEEE NS-28, No 3, June 1981, pp 2806

[3] JW Glenn, et. al., "Mini-Bunching the AGS Slow External Beam", these proceedings.